Modelling and Forecasting the USD-INR Exchange Rate Using MLR and ARIMA Approaches

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Abstract: Exchange rate fluctuations are a critical element in the economic performance of open economies, as they influence international trade, capital flows, investment planning, and policy development. For India, managing currency volatility is essential due to its increasing engagement in global markets. The Reserve Bank of India (RBI) frequently intervenes to regulate extreme movements in the exchange rate to safeguard macroeconomic stability. This study focuses on examining the USD-INR exchange rate in relation to four key macroeconomic variables: inflation rate, interest rate, unemployment rate, and GDP growth rate, considering both Indian and U.S. perspectives. To achieve this, two Multiple Linear Regression (MLR) models were constructed using annual data from 1991 to 2021, allowing for the assessment of each variable's statistical influence and directional effect on the exchange rate. Alongside this, a time-series analysis was conducted using the ARIMA (Auto Regressive Integrated Moving Average) model to forecast monthly exchange rates, offering insights into future currency trends based on historical data patterns. The analysis revealed that macroeconomic indicators from the United States have a more substantial impact on the USD-INR exchange rate than those from India, underscoring the Indian rupee's sensitivity to global economic conditions. The ARIMA (1,1,1) model emerged as the most suitable for forecasting purposes, providing reliable projections for the years 2021 and 2022.Overall, this research highlights the interconnected nature of global economies and emphasizes the importance of combining regression analysis with time-series forecasting to gain a comprehensive understanding of exchange rate behavior. The findings provide valuable input for policymakers, investors, and businesses engaged in international operations, as they navigate currency-related risks and develop informed strategies in a volatile global environment.

Keywords: Exchange Rate, ARIMA, Multiple Linear Regression, Macroeconomic Indicators, USD-INR

I. Introduction

Exchange rates form the backbone of international economic transactions, functioning as dynamic indicators of a country's financial standing and its interaction with the global market. For a rapidly evolving economy like India, the exchange rate—especially with respect to the US Dollar—has emerged as a critical macroeconomic variable influencing trade balances, capital flows, price stability, and fiscal planning. The USD-INR rate, in particular, holds strategic importance due to the United States' dominant position in global trade and finance, and India's growing dependence on external trade, oil imports, remittances, and foreign investments. Over the past three decades, the Indian rupee has undergone substantial shifts in value, shaped by a combination of internal policy decisions, global financial trends, and economic disruptions. Events such as the 1991 economic liberalization, global financial crises, changes in monetary policy stances by central banks, and recent geopolitical tensions have collectively contributed to exchange rate volatility. Understanding these fluctuations is not merely an academic exercise—it is a practical necessity for governments formulating trade policy, for investors managing currency risk, and for businesses engaged in cross-border operations. This study is motivated by the need to unravel the key macroeconomic determinants that drive exchange rate movements over time and to build a robust model capable of forecasting future trends. Specifically, we focus on the bilateral exchange rate between the Indian rupee and the US dollar, analyzing the influence of four fundamental economic indicators: inflation rate, interest rate, unemployment rate, and GDP growth. Recognizing that both domestic and foreign economic conditions shape exchange rate behavior, we incorporate variables from both India and the United States to provide a comparative and holistic perspective.

Methodologically, this research adopts a two-pronged approach. First, Multiple Linear Regression (MLR) models are constructed to quantify the relationship between exchange rates and the selected macroeconomic variables, allowing us to identify which factors exert significant influence. Second, a Time Series Forecasting method, specifically the **ARIMA** (Auto Regressive Integrated Moving Average) model, is applied to historical monthly exchange rate data spanning from 1991 to 2021. This model enables us to capture underlying patterns such as trends and seasonality, and project future values with statistical confidence. By integrating cross-country macroeconomic analysis with time series forecasting, this paper aims to provide actionable insights into exchange rate dynamics, with practical implications for economic planning, corporate strategy, and financial risk . The findings also contribute to the academic discourse on exchange rate modeling in emerging economies, highlighting the relative importance of domestic versus foreign economic indicators in shaping currency valuation.

Statement of the Problem:

The exchange rate between the Indian Rupee (INR) and the United States Dollar (USD) has exhibited persistent volatility over the past three decades, influenced by both domestic economic conditions and global financial forces. This fluctuation poses significant challenges for policymakers, investors, multinational corporations, and import-export businesses in planning, forecasting, and risk

management. Despite numerous studies on exchange rate behavior, there remains a lack of integrative research that simultaneously examines the macroeconomic determinants from both countries and applies robust time series forecasting techniques tailored to the Indian context. Furthermore, much of the existing empirical literature either focuses exclusively on historical trend analysis or models exchange rate determinants in isolation, without combining regression-based inference with forward-looking forecasting models. As a result, there is a gap in comprehensive studies that employ both structural modeling—such as Multiple Linear Regression (MLR)—and data-driven forecasting techniques—such as AutoRegressive Integrated Moving Average (ARIMA)—to capture both the drivers and the trajectory of the exchange rate. Given the increasing exposure of India's economy to global markets and the centrality of the USD-INR exchange rate in shaping external trade and capital flows, there is a pressing need to identify the macroeconomic indicators that significantly influence exchange rate behavior and to develop accurate, data-informed models for prediction. This study seeks to address this gap by systematically analyzing the impact of inflation, interest rates, unemployment, and GDP growth—both from India and the U.S.—on exchange rate dynamics, and by constructing a reliable forecasting framework to anticipate future movements in the USD-INR rate.

II. Literature Review

Empirical Review

Exchange rate dynamics have long been a central theme in international economics due to their impact on trade competitiveness, foreign investment flows, inflation, and economic growth. The USD-INR exchange rate, in particular, has drawn increasing attention in recent decades as India's economy has progressively liberalized and integrated with global markets. With the rise in external trade, capital account openness, and foreign direct investment, understanding the determinants and behavior of the rupee-dollar exchange rate has become critical for informed decision-making by policymakers and businesses. Several studies have attempted to model exchange rate behavior through various macroeconomic variables. Traditional theoretical frameworks such as Purchasing Power Parity (PPP), the Monetary Approach to Exchange Rates, and the Balance of Payments approach emphasize the role of inflation, interest rate differentials, and trade balances in determining currency values. While these models offer foundational insights, their empirical validity—particularly in the context of emerging economies like India—has shown mixed results due to market imperfections, capital controls, and external shocks.

Empirical studies have increasingly turned to data-driven statistical models to capture the complex relationship between macroeconomic indicators and exchange rates. Multiple Linear Regression (MLR) has been widely applied to quantify the influence of economic variables such as inflation, interest rates, GDP growth, and unemployment on exchange rates. These models help identify which factors have statistically significant relationships with currency fluctuations, though they are often limited by assumptions of linearity and stationarity. Time-series methods such as ARIMA (AutoRegressive Integrated Moving Average) have gained prominence in the domain of exchange rate forecasting. Unlike structural models, ARIMA focuses on the internal properties of the data, such as trends and autocorrelations, and is particularly effective in short-term prediction scenarios. Studies applying ARIMA to exchange rate data have demonstrated its usefulness in forecasting, especially when the data exhibit non-stationary behavior and irregular seasonal trends. Despite the depth of existing literature, few studies integrate both regression-based determinant analysis and ARIMA-based forecasting in a unified framework—especially with macroeconomic variables from both domestic and international sources. Moreover, much of the available research either focuses on developed economies or analyzes Indian exchange rates using limited variables or shorter time spans. This study builds upon the existing literature by jointly employing MLR and ARIMA methodologies to examine and forecast the USD-INR exchange rate using a comprehensive dataset from 1991 to 2021. By incorporating macroeconomic indicators from both India and the United States, the research offers a dual-perspective approach that reflects the bilateral nature of exchange rate behavior. This integrated model aims to contribute to both the academic literature and practical financial decision-making, especially in the context of emerging market economies.

Theoretical Framework:

Foreign exchange rates play a pivotal role in determining a country's macroeconomic stability and international trade dynamics. The fluctuation of currency values influences a wide spectrum of economic variables such as inflation, interest rates, employment levels, and GDP growth. Consequently, comprehending the theoretical underpinnings that connect these macroeconomic indicators to exchange rate movements is essential for effective economic planning, policy formulation, and business strategy.

This study draws upon theories from international finance and macroeconomics, particularly the Purchasing Power Parity (PPP) theory, the Interest Rate Parity (IRP) theory, and macroeconomic balance models, all of which provide a framework for understanding currency valuation and its predictors.

I. Purchasing Power Parity (PPP): This theory posits that in the long run; exchange rates should adjust to equalize the price levels of two countries. In practice, inflation differentials influence the currency's value—higher domestic inflation tends to depreciate the currency.

II. Interest Rate Parity (IRP): According to IRP, the difference in interest rates between two countries is equal to the expected change in exchange rates between their currencies. A country offering higher interest rates attracts foreign capital, which can lead to currency appreciation, although inflation expectations and risk premiums complicate this relationship.

III. Macroeconomic Determinants Model: This model suggests that exchange rates are influenced by a combination of macroeconomic indicators such as interest rates, inflation rates, GDP growth, and unemployment. These variables collectively signal the economic health and investment appeal of a country, which in turn affects the demand and supply of its currency in the global market.

In alignment with these theories, the current study incorporates four key macroeconomic indicators—Inflation Rate, Interest Rate, Unemployment Rate, and GDP Growth Rate—as potential explanatory variables affecting the USD-INR exchange rate over the period 1991 to 2021. The research adopts Multiple Linear Regression (MLR) to evaluate the strength and nature of these relationships and applies ARIMA (Auto-Regressive Integrated Moving Average) modeling to forecast future exchange rate trends based on historical data.

This dual-modelling approach—causal and predictive—enables the study not only to understand which economic forces have historically driven the exchange rate but also to anticipate its likely future trajectory under similar conditions. By grounding the empirical work in robust economic theory, the study ensures analytical rigor and practical relevance in the volatile domain of foreign exchange markets.

Conceptual Framework:

1. Independent Variables (Macroeconomic Factors):

These are the explanatory variables believed to influence the exchange rate:

- Inflation Rate

(↑ Inflation → ↓ Currency Value)

- Interest Rate

(↑ Interest → ↑ Currency Value due to capital inflows)

- Unemployment Rate

(↑ Unemployment → ↓ Investor Confidence → ↓ Currency Value)

- GDP Growth Rate

(↑ GDP → ↑ Economic Strength → ↑ Currency Demand)

2. Dependent Variable:

- USD–INR Exchange Rate

The monthly average exchange rate of Indian Rupee per US Dollar.

3. Analytical Methods:

- Multiple Linear Regression (MLR):

Used to quantify the impact of each macroeconomic factor on the exchange rate.

- ARIMA Model:

Used for time series forecasting of future exchange rates based on historical data trends and patterns.

4. Hypothesized Relationships:

Independent Variable	Expected Effect on Exchange Rate (INR/USD)
Inflation Rate	Positive or Negative (depends on relative inflation)
Interest Rate	Negative (Higher rates attract capital inflows)
Unemployment Rate	Positive (Higher unemployment may weaken the currency)
GDP Growth Rate	Negative (Higher growth may strengthen the INR)

III. Methodology

Research Methodology:

The present study employs a quantitative research methodology to examine and forecast the USD–INR exchange rate over the period 1991 to 2021. The study integrates two primary analytical approaches: multiple linear regression (MLR) to investigate the relationship between key macroeconomic variables and the exchange rate, and time series analysis using the ARIMA model to forecast future exchange rate trends. Data for the analysis were obtained from two authoritative sources. Monthly exchange rate

data (USD–INR) were collected from the Reserve Bank of India (RBI) database, while annual macroeconomic indicators—namely, inflation rate, interest rate, unemployment rate, and GDP growth rate—were sourced from the World Bank Open Data platform. These variables were selected based on their theoretical and empirical relevance in explaining foreign exchange rate fluctuations, as established in the literature on international finance. The dependent variable in this study is the USD–INR exchange rate, while the independent variables include inflation rates, interest rates, unemployment rates, and GDP growth rates for both India and the United States. These indicators were analyzed to evaluate their influence on the exchange rate, considering the economic interdependence between the two countries. For the purpose of forecasting, the study utilized the Auto-Regressive Integrated Moving Average (ARIMA) model. Initial steps involved plotting the exchange rate time series to identify trends and patterns. Stationarity of the time series was assessed using the Augmented Dickey-Fuller (ADF) test. To ensure stationarity, differencing was applied as needed. The optimal ARIMA model was selected using the auto.arima () function in R, with model adequacy checked via residual diagnostics and the Ljung–Box Q-test. The final model, ARIMA (1,1,1), was then used to generate forecasts for the exchange rate for the years 2021 and 2022.To examine the influence of macroeconomic indicators on exchange rate movements, multiple linear regression models were developed separately for Indian and U.S. variables. The regression model considered the exchange rate as the dependent variable and the four macroeconomic indicators as independent variables. Statistical significance of the overall model and individual predictors was assessed using F-tests and t-tests, respectively. Diagnostic tests were conducted to ensure that the regression assumptions were satisfied. These included the Shapiro–Wilk test for normality of residuals, the Breusch–Pagan test (or NCV test) for homoscedasticity, and a visual inspection of residual plots. All data analysis, modeling, and visualization tasks were conducted using the R programming language, which offers robust tools for time series analysis and regression modeling. This methodological framework allowed the study to explore both causal relationships and predictive insights into the USD–INR exchange rate, offering valuable inputs for economic strategy and policy formulation.

Data Availability:

For Exchange Rates – https://dbie.rbi.org.in/DBIE/dbie.rbi?site=statistics (Monthly Data from 1991-2021)

IV. Key Findings and Discussions

The analysis of the USD–INR exchange rate over the period 1991 to 2021 yielded several insightful findings. Using a combination of time series forecasting and multiple regression analysis, the study provided both predictive and explanatory understanding of exchange rate behavior in the Indian context. The ARIMA (1,1,1) model was found to be the most appropriate model for forecasting monthly exchange rates. The model selection was based on minimizing AIC and BIC criteria and confirmed through diagnostic checks like the Ljung–Box test for autocorrelation in residuals. The time series data, after differencing, satisfied the stationarity assumption as validated by the Augmented Dickey-Fuller (ADF) test. The ARIMA model exhibited a good fit with minimal forecast error, and the projections for the years 2021 and 2022 closely aligned with observed values, indicating the robustness of the model for short-term forecasting. On the other hand, the multiple linear regression analysis offered deeper insights into the macroeconomic determinants of the exchange rate. Two separate regression models were constructed: one incorporating the macroeconomic indicators of the United States and the other with those of India. The findings indicated that the U.S. factors—inflation rate, interest rate, and unemployment rate—had a statistically significant negative impact on the USD–INR exchange rate. This implies that improvements in U.S. economic conditions are generally associated with a stronger dollar and a weakening Indian rupee. Interestingly, the GDP growth rate of the USA was found to be statistically insignificant, suggesting that short-term growth changes may not directly influence exchange rate movements. In the regression model based on Indian indicators, the inflation rate and interest rate were found to be significant predictors, with both having a negative relationship with the exchange rate. This indicates that rising domestic inflation or interest rates tend to depreciate the Indian rupee against the U.S. dollar. However, unlike the U.S. model, unemployment rate in India showed a positive association, and GDP growth rate was statistically insignificant. The Indian model explained a relatively smaller proportion of exchange rate variability ($R^2 \approx 48\%$) compared to the U.S. model ($R^2 \approx 75\%$), implying that the exchange rate is more sensitive to global (particularly U.S.) economic conditions than to domestic ones. These results suggest that external economic factors, especially those originating in the United States, play a more dominant role in determining the USD–INR exchange rate than internal Indian factors. This aligns with India's position as an emerging market with substantial exposure to global trade, capital flows, and financial policies of advanced economies. The findings underscore the importance of tracking international economic signals for effective exchange rate management and highlight the need for policymakers to consider global dynamics while formulating domestic economic strategies.

Overall, the study demonstrates the utility of statistical models in understanding and forecasting foreign exchange movements and contributes valuable insights for investors, economists, and policy advisors.

V. Time series Analysis

The present study provides a comprehensive statistical analysis of the USD–INR exchange rate by evaluating its historical behavior and identifying macroeconomic determinants through time series modeling and multiple linear regression. The project employs monthly exchange rate data from 1991 to 2021 and explores the influence of key economic indicators—namely inflation rate, interest rate, unemployment rate, and GDP growth rate—from both India and the United States. The time series analysis began with decomposition to understand the underlying patterns in the data. The exchange rate series exhibited a clear upward trend, consistent with a long-term depreciation of the Indian Rupee. The series was found to be non-stationary based on the Augmented Dickey-Fuller (ADF) test. Differencing was applied to achieve stationarity, after which the ARIMA (1,1,1) model was selected using the

auto. arima () function in R. Model adequacy checks using residual diagnostics and the Ljung–Box Q test confirmed the validity of the model. Forecasting with this model for the years 2021 and 2022 yielded results closely aligned with observed data, suggesting the model's practical usefulness for short-term exchange rate prediction. In addition to forecasting, the study employed multiple linear regression (MLR) to explore the structural relationship between exchange rates and macroeconomic variables. Two models were constructed separately—one using U.S. indicators and another using Indian indicators. The regression model with U.S. variables revealed that inflation rate, interest rate, and unemployment rate had statistically significant negative impacts on the exchange rate, indicating that strengthening U.S. economic conditions are associated with a stronger dollar and a weaker rupee. The GDP growth rate of the U.S., however, was not a significant predictor. The model using Indian macroeconomic indicators showed that inflation and interest rates were significant predictors of exchange rate changes, while GDP growth rate was not. Interestingly, unemployment in India had a positive coefficient, suggesting a complex or possibly indirect relationship between labor market conditions and currency valuation. The U.S. model demonstrated stronger explanatory power with an R^2 value of 75%, as compared to 48% for the Indian model. This indicates that external (U.S.) economic factors have a more pronounced influence on the USD–INR exchange rate than internal Indian variables, reinforcing the idea that India's exchange rate is significantly affected by global market dynamics. Overall, the analytical results validate the use of ARIMA for short-term forecasting and MLR for understanding macroeconomic linkages. The study underscores the importance of monitoring international economic signals, particularly those from the United States, for effective exchange rate management in India. The results also suggest that policymakers should focus not only on domestic fundamentals but also account for global economic conditions while formulating monetary and trade policies.

VI. Conclusion and Recommendations

This study set out to analyze and forecast the USD–INR exchange rate over the period 1991 to 2021 by incorporating both time series and multivariate regression approaches. Based on monthly exchange rate data and annual macroeconomic indicators from India and the United States, the investigation yielded meaningful insights into the behavior and determinants of currency fluctuations. The ARIMA (1,1,1) model emerged as the most suitable for modeling the time-dependent structure of exchange rate data. The model captured underlying trends and irregularities effectively and produced reliable forecasts for the year 2022. These predictions are particularly valuable for anticipating future trade and capital flow dynamics, offering actionable intelligence for businesses, investors, and policy makers. The multiple linear regression analysis further enhanced the understanding of structural influences on exchange rate movements. The model based on U.S. macroeconomic indicators demonstrated a strong explanatory power, with inflation rate, interest rate, and unemployment rate significantly affecting the exchange rate. In contrast, the regression model based on Indian economic factors showed that only inflation and interest rates had statistically significant impacts. Notably, the GDP growth rate for both India and the United States was found to be statistically insignificant in influencing exchange rate movements within the study period. A key conclusion drawn from the comparative analysis is that the volatility in the USD–INR exchange rate is predominantly driven by external (U.S.) economic factors rather than domestic ones. This reinforces the reality that emerging economies like India are highly sensitive to global macroeconomic shifts, especially those originating from major financial centers such as the United States. In summary, the research effectively demonstrates that a combination of time series forecasting and regression modeling provides a robust framework for understanding and predicting exchange rate fluctuations. It highlights the necessity for India to align its economic monitoring and policy response not just with domestic trends, but also with global developments that have a direct bearing on its currency valuation.

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